

## Appendix C Design

### C-1. Introduction

Dams are unique because the design function can never be considered finished as long as the dam remains in place. Because of the many unknowns usually encountered, construction (and operation) must be a continuation of design. Foundation and borrow work during construction provide far better exploration than is available during design, and changes which impact safety are common. Design personnel should visit the site during construction to confirm that site conditions conform to those assumed in design or to determine if design changes are required to suit the actual conditions. Operational design inspections should continue throughout the life of the project. The design function includes planning dam instrumentation to be installed during construction and/or operation to monitor conditions that could potentially threaten the safety of the dam (Federal Emergency Management Agency 1979). The general design and construction of earth and rock fill dams are discussed in EM 1110-2-2300 and EM 1110-2-1911. The design of gravity dams is given in EM 1110-2-2200.

### C-2. Design Review

All designs accomplished by an Engineering District will be reviewed by an independent, multi-discipline team. About 80 percent of Corps dam designs are accomplished internally and about 20 percent are accomplished externally by contract with private engineering firms (Federal Emergency Management Agency 1992b; U.S. Army Corps of Engineers, Office of the Chief of Engineers 1977).

### C-3. Instrumentation Plan

*a. General.* All Corps of Engineers dams are required to have an adequate level of instrumentation to enable the designers to monitor and evaluate the safety of the structure during the construction period

and under all operating conditions. Visual observations and the interpretation of instrumentation data provide the primary means for engineers to evaluate dam safety. Recently, technology of devices for measuring seepage, stresses and movements and pore water pressures in dams has improved significantly with respect to accuracy, reliability and economics. The planning, design, and layout of an instrumentation program is an integral part of the project design. Guidance on the selection and use of various types of instrumentation for earth and rockfill dams is given in EM 1110-2-2300 and EM 1110-2-1908. Guidance on the instrumentation for concrete dams is given in EM 1110-2-1908 and EM 1110-2-4300 (see also Lindsey et al. 1986, Keeter et al. 1986, Currier and Fenn 1986, O'Neil 1989). Additional information on instrumentation of dams is available (United States Committee on Large Dams 1984 and 1986, Colorado Division of Disaster Emergency Services 1987, Federal Energy Regulatory Commission 1991, Carpenter et al. 1988).

*b. Types of instrumentation.* The type, number, and location of required instrumentation depend on the complexity of the project. For earth and rockfill dams, the types of measurements generally include the following (EM 1110-2-2300 and EM 1110-2-1908):

(1) Piezometers (open tube, such as the Casagrande type, electrical, vibrating wire, or occasionally closed systems; located in the foundation, abutment, and/or embankment).

(2) Surface monuments.

(3) Settlement plates within the embankment.

(4) Inclinometers (slope indicators).

(5) Movement indicators (at conduit joints, outlet works, and intake tower).

(6) Internal vertical and horizontal movement and strain indicators.

(7) Earth pressure cells.

(8) Strong motion accelerometers (in areas of seismic activity).

(9) Weirs, flow meters and flumes to measure seepage clarity and quantity.

For concrete dams, the types of measurements (and instruments) include (EM 1110-2-2200 and EM 1110-2-4300):

(1) Strain and deflection (internal and/or external gages).

(2) Crack or joint movement (internal and/or external gages).

(3) Stress and pressure (stress meter, pressure gage, pressure cell).

(4) Uplift pressure (standpipe and/or diaphragm uplift cell, water level indicator).

(5) Hydraulic leakage from foundation drains, joint drains and face drains (v-notch weir and/or critical depth meter).

(6) Plumbness and levelness (plumb lines, optical plummets, electrolevel and water level meter).

(7) Alignment, settlement, and distance (laser, theodolite, triangulation, trilateration and electronic distance meters).

(8) Seismic time history and magnitude (strong motion and peak reading accelerometers and hydrodynamic pressure gages).

(9) Temperature (resistance thermometer and thermocouples).

*c. Automatic data acquisition.* Consideration should be given to providing a computer-based automated data acquisition system (ADAS) to provide cost-effective real time data collection from the dam. General guidance for developing an ADAS for earth and rockfill dams is presented in Appendix D of EM 1110-2-2300. A comprehensive review of ADAS for concrete structures was made under the Corps of Engineers Repair, Evaluation,

Maintenance, and Rehabilitation (REMR) Program (Lindsey et al. 1986, Keeter et al. 1986, Currier and Fenn 1986, O'Neil 1989). Topics covered include design requirements, signal conditioning and processing, data transmission and reduction, system installation and maintenance, retrofitting existing instruments to automation and computer hardware and software used to drive the automated instruments and reduce and report the collected data (U.S. Army Corps of Engineers 1987). A data base for automated geotechnical and some structural instrumentation at Federal and non-Federal projects is maintained under the Corps of Engineers Computer Applications in Geotechnical Engineering (CAGE) Program.

*d. Instrumentation plan and records.* During the initial project design, or reevaluation in the case of existing structures, the physical properties of the construction materials, design data, loading conditions and the appropriate factors of safety will be utilized to determine the desired threshold limits for the design condition. Quantitative values will be established for these limits that can be accurately translated into measurements that are readily obtained in the field, which will enable the designers and operators to evaluate the behavior and performance of the structure. The threshold limits along with the predicted performance levels will be addressed in the project instrumentation design memorandum. General guidance on preparation of the instrumentation design memorandum is given in EM 1110-2-2300 and ER 1110-2-110. ER 1110-2-1925 prescribes the forms to use in recording instrumentation observations. Additional information on instrumentation and monitoring is given in Chapter 4.

#### **C-4. Coordination Between Design and Construction**

Close coordination between design and construction personnel is necessary to thoroughly orient the construction personnel as to the project design intent; ensure that new field information, acquired during construction, is assimilated into the design; and ensure that the project is constructed according to the intent of the design (U.S. Army Corps of Engineers, Office of the Chief of Engineers 1977).

*a. Report on engineering considerations and instructions to field personnel.* Design personnel (geologists, geotechnical engineers, structural engineers, etc.) will prepare a report to aid the construction engineers in supervision and inspection of the construction of the dam (ER 1110-2-1150).

*b. Preconstruction orientation.* Preconstruction orientation for the construction engineers by the designers is necessary for the construction engineers to be aware of the design philosophies and assumptions regarding site conditions and function of project structures, and to understand the design engineers' intent concerning technical provisions in the P&S (Federal Emergency Management Agency 1979).

*c. Construction milestones which require visit by designers.* Visits to the site by design and design review personnel are required to ensure the following (ER 1110-2-112, ER 1110-2-1150):

(1) Site conditions throughout the construction period are in conformance with design assumptions and principles as well as contract P&S.

(2) Project personnel are given assistance in adapting project designs to actual site conditions as they are revealed during construction.

(3) Any engineering problems not fully assessed in the original design are observed, evaluated, and appropriate action taken.

Specifically, site visits are required when the following occur (ER 1110-2-112):

(1) Excavation of cutoff trenches, foundations, and abutments for dams and appurtenant structures.

(2) Excavation of tunnels.

(3) Excavation of borrow areas and placement of embankment dam materials early in the construction period.

(4) Observation of field conditions that are significantly different from those assumed during design.

*d. Ensure project is constructed according to intent of design.* The Corps of Engineers has several cost-saving programs. One of these programs which can affect dam safety is Value Engineering (VE). The VE process provides for a multi-discipline team of engineers to develop alternative designs for some portion of the project. The construction contractor can also submit VE proposals. Any VE proposal affecting the design is to be evaluated by design personnel prior to implementation to determine the technical adequacy of the proposal. VE proposals must not adversely affect the long-term performance or condition of the dam. A potential safety problem exists if design personnel do not have the opportunity for evaluation (U.S. Army Corps of Engineers, Office of the Chief of Engineers 1977).